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(54) **Title**: SYSTEM FOR PROTECTION AGAINST STORMS

(57) **Abstract**: The invention relates to a system for protecting a structure against high winds of a hurricane category, said system comprising at least one panel, said panel comprising a strike face for receiving an impact and furthermore said system comprising means for attaching the system to or for positioning the system in close proximity to said structure, characterized in that said strike face comprises a compressed sheet, said sheet being substantially rigid and wherein said sheet contains a plurality of layers of fabric, said fabric containing high strength fibers. The invention also relates to a method of mounting the inventive system to a structure, the method comprising connecting the system according to the invention to or in close proximity to said structure.

SYSTEM FOR PROTECTION AGAINST STORMS

The invention relates to a system for protecting a structure against high winds of a hurricane category, said system comprising at least one panel, said panel comprising a strike face for receiving an impact and furthermore said system comprising means for attaching the system to or for positioning the system in close proximity to said structure. The invention also relates to a method of installing said system.

The need for protecting structures, and in particular buildings, in regions that are subject to hurricanes and other storms capable of significantly damaging said structures is increasingly recognized. The aim in providing storm resistant protective systems is to provide a system which prevents high velocity winds as well as flying debris carried by the same cannot damage the walls of the structure or even enter the structure by penetrating an opening thereof.

A known system for protecting a structure against high winds of a hurricane category, referred to for simplicity as protective system, is described for example in US 6,974,622. This publication discloses a system comprising a plurality of corrugated plastic sheets and mounting means for attaching said system to a structure.

A further disclosure of a protective system is given by US 6,189,264 wherein a storm shutter system is detailed. Said shutter system comprises retaining means for attaching said system to a structure and a plurality of metal or polycarbonate panels wherein each panel is attached to at least one adjacent panel.

A somewhat different concept of a protective system was employed by US 7,446,064. The disclosure thereof concerns reinforced building panels for use in constructing a structure, e.g. a dwelling, and which are a permanent component of said structure. The building panels of US 7,446,064 are metal composite panels comprising a reinforcing fabric containing polymeric fibers, in particular aramid fibers, sandwiched between two metal plates. Further alike building panels similar to those of the aforementioned publication are known for example from US 2006/0150554 wherein a panel is disclosed containing two exterior layers of structural sheathings from hard or soft woods, plywood or cement, said layers holding a plastic material, adhesive layers and a reinforcing fabric sheet therein between.

US2006/0086057 describes a protective window covering, in particular a convex protective storm window. It is described that the convex panel can be constructed out of fiberglass, plastic, metal or other suitable material, in particular a high strength plastic, such as Kevlar. This document describes how the protective storm window can be fixed to a frame but it does not give any indication on how the convex window could be manufacture from the high strength plastic.

US2003/0134091 describes a corrugated sheet for protecting windows and doors of a walled structure. The sheet can be made of a suitable polyolefin by means of an extrusion process.

US2008/0313979 relates to a storm panel made of a high strength fabric that can be rolled up when not in use. The high strength fabric can be made of high strength yarn such al ultra high molecular weight polyethylene.

It was, observed that a common problem of protective systems such as the ones disclosed above is that their lifetime is too short and they need be replaced rather often. It was furthermore observed that their resistance to impact by heavy airborne debris, i.e. debris having a mass of above 1 kg, is also reduced.

It was also observed that systems such as the ones disclosed by US 6,189,264 are heavy and difficult to install and once installed they must be kept in place since a single person cannot raise them into place in due time only by himself. It was furthermore noticed that such systems impair the esthetic of the building on which they are mounted on and are subject to corrosion.

It was also observed that panels and in particular permanently installed panels similar to those disclosed by US 7,446,064 in additions to the fact that they are prone to corrosion, they can only be mounted in place with the aid of rather heavy machinery. It was furthermore observed that panels such as those according to US 2006/0150554 show a decreased resistance against impacting debris which have sharp corners and in particular against heavy such debris. It was also observed that the exterior layers of sheeting are easily pierced or damaged by impacts even from sharp lightweight impacting debris and therefore the entire panel need be immediately replaced. Furthermore, it was observed that all of the above mentioned panels are rather difficult to produce.

It is therefore an aim of this invention to provide a protective system which is lightweight and can be easily and rapidly mounted even by a single person. It is also aimed to provide a protective system able to withstand multiple impacts from high speed, heavy airborne debris, e.g. debris having a mass of above 1 kg and flying at speeds above about 15 m/s (above about 40 miles/hour). It is also aimed to provide a protective system which resists the impact of sharp debris without being pierced or irreversibly damaged. It is also aimed to provide a protective system which upon impact has a lower back face deformation than known systems, i.e. a protective system that has an increased resistance to bending and buckling when impacted by airborne debris and in particular by heavy airborne debris. It is also an aim of the present invention to provide a protective system which can be at least temporarily installed on a structure or a building and which after its removal leaves the building substantially unaffected by impacts, eliminating therefore the need for subsequent maintenance repairs on said structure or building.

The invention therefore provides a system for protecting a structure against high winds of a hurricane category, said system comprising at least one panel, said panel comprising a strike face for receiving an impact and furthermore said system comprising means for attaching the system to or for positioning the system in close proximity to said structure, characterized in that said strike face comprises a compressed sheet, said sheet being substantially rigid and wherein said sheet contains a plurality of layers of fabric, said fabric containing high strength fibers.

It was observed that the system according to the invention, also referred to as the inventive system, is lightweight and can be installed easily even by a single person in a short period of time. It was also observed that the resistance of the inventive system to impacts from airborne debris and in particular from heavy airborne debris is improved in comparison with known protective systems even when said debris impact said system with sharp corners. Further advantages of the inventive system will become apparent from the details of the invention presented herein below.

According to the invention, the inventive system comprises a panel. By panel is herein understood a constitutive element of the inventive system which has the purpose of protecting a structure or part of a structure against impacts from airborne debris.

Good results were obtained when the panel contained by the inventive system had an areal density (AD) of at least 1000 g/m^2, more preferably of at least 3000 g/m^2, most preferably of at least 5000 g/m^2.

According to the invention, the panel contained by the inventive system contains a strike face for receiving an impact. The strike face is herein understood the face of the panel which is the first to receive an impact, and although referred to as face, it is understood that said face is not restricted to having a limited thickness but it may have a thickness that may even be as large as the thickness of the panel itself.

According to the invention the strike face contains a compressed sheet, said sheet being substantially rigid. Said sheet is referred hereinafter to, for simplicity, as the rigid sheet. In a preferred embodiment, the rigid sheet contained by the strike face is positioned at an outside of said strike face such that said rigid sheet receives first an airborne debris impacting said panel. It was observed that a panel having such a strike face is less damaged by impacts from debris even in case of heavy weight debris.

By a rigid sheet is herein understood a sheet that is firm or inflexible enough to resist being plied or folded during normal manipulation and use. The advantage of such a protective system is that it deforms less when impacted by debris and therefore, it can be attached directly to the structure to be protected or even placed in close proximity thereof.

Preferably, the rigid sheet contains at least 2 fabrics, more preferably at least 4 fabrics, most preferably at least 6 fabrics, said fabrics being preferably stacked such that they overlap over substantially their whole surface area. Alternatively, the rigid sheet can contain a single piece of fabric folded over itself at least 2 times, more preferably at least 4 times, most preferably at least 6 times, all folds having preferably the same length (L) and width (W). It was observed that sheets containing an increased number of fabrics showed further improved bending modulus as well as an increased resistance to impacts with various fast moving objects, e.g. shrapnel or bullets, or slow moving objects, e.g. the forks of a forklift truck.

When at least two fabrics are used to manufacture the rigid sheet, the fabrics may be arranged such that the orientation direction of a first majority of fibers in a fabric is under an angle of between 0 and 90° with respect to the orientation direction of a first majority of fibers in an adjacent fabric, more preferably said angle being between 30 and 90°, most preferably between 45 and 90°. When the fabric used to construct the rigid sheet is a woven fabric, preferably, the orientation direction of the warp fibers in a fabric is at an angle of between 30 and 90°, most preferably of between 45 and 90° with the orientation direction of the warp fibers in an adjacent fabric. When the fabrics used to construct the rigid sheet are non-woven, said non-woven fabrics are preferably layered fabrics comprising at least one layer, said layer comprising two monolayers wherein the monolayers comprise unidirectionally oriented fibers and wherein the monolayers are orientated at an angle with respect to each other of between 15 and 90°, more preferably of between 30 and 90°, most preferably of between 45 and 90°. Methods of manufacturing such layered non-woven fibers are disclosed for example in WO 02/057527; EP 0,768,167; DE 197,07,125; DE-A-23,20,133.

The fabrics and in particular the non-woven fabrics may also contain a binder, also known as matrix, which is usually locally applied to stabilize the polymeric fibers within the fabric such that the structure of the fabric is retained during handling. Said binders may also be used to promote adhesion between the fabrics when more than two fabrics are used to construct the rigid sheet.

Suitable binders are described in e.g. EP 0,191,306; EP 1,170,925; EP 0,683, 374; WO 2009/008922 and EP 1,144,740 and include Polyethylene-P0440 1, Polyethylene-P04605 10, Polyethylene-D0 184B, Polyurethane-D0 187H, and Polyethylene-D0188Q, which are all available from Spunfab, Ltd. of Cayahoga Falls, Ohio; Kraton D1 161P, which is available from Kraton Polymers U.S., LLC of Houston, Texas; Macromelt 6900, which is available from Henkel Adhesives of Elgin, Illinois; and Noveon-Estane 5703, which is available from Lubrizol Advanced Materials, Inc. of Cleveland, Ohio. The amount of the binder is preferably at most 20 wt%, more preferably at most 10 wt%, most preferably at most 5 wt%.

In a preferred embodiment the fabric used to manufacture the rigid sheet is a woven fabric, said woven fabric being binder- or matrix-free.

Particularly useful is a sheet as described in PCT/EP2010/055337, incorporated by reference herein.

Preferably the rigid sheet has a bending modulus of at least 2 GPa when measured according to ASTM D790-07, more preferably of at least 5 GPa, even more preferably of at least 15 GPa, most preferably of at least 30 GPa when measured according to ASTM D790-07 in at least two directions (2D bending modulus) and wherein one of said directions is the orientation direction of a first majority of the fibers contained by said at least one woven or non-woven fabric.

Preferably, the bending modulus of the rigid sheet has values within the aforementioned ranges when measured along at least two directions within the plane of the sheet, one direction thereof being along an orientation direction of a majority of fibers in the sheet, i.e. the orientation direction of at least 10 mass% of the fibers in the sheet. The skilled person can determine for example visually said orientation direction of fibers, e.g. with the help of a microscope.

The measurements on 2D bending modulus can be carried out on samples extracted from the sheet of the invention by cutting, the cutting being performed with a high pressure water jet to ensure smooth edges of the sample, said samples preferably having a length (l) over thickness (d) ratio (l/d) of about 24. Preferably, the thickness of the sample is between 1.75 and 1.95. The length (l) of the extracted samples was cut along the direction of measurement. The skilled person can produce sheets having such high 2D bending modulus according to a process as detailed hereinafter.

The rigid sheet preferably has a 2D flexural strength, i.e. the flexural strength measured in two directions, of at least 50 MPa, more preferably at least 80 MPa, most preferably at least 100 MPa as determined by ASTM D790-07 on a sample having a length (l) over thickness (d) ratio (l/d) of 24. Preferably, the thickness of the sample is between 1.75 and 1.95.

It was observed that the inventive system deforms less than known protective systems when impacted even by heavy airborne debris, substantially without running the risk of damaging the protected structure behind said system due to excessive buckling and/or bending thereof. It was also observed that the system is less affected than known systems by high velocity winds, i.e. it vibrates less in the wind and does not buckle under the force of the wind.

According to the invention, the 2D bending modulus is measured in at least two directions one of which being along the orientation direction of a first majority of the fibers contained by said fabric. An orientation direction of a majority of fibers is herein understood a common orientation direction of preferably at least 10 mass% of the fibers contained by the fabric, more preferably at least 30 mass%, most preferably at least 50 mass %. By mass% is herein understood the percentage of the fibers oriented in a common direction, said percentage being computed from the total mass of fibers oriented in all possible direction and being contained by the fabric. Said orientation direction can be determined for example by visually inspecting the fibers or with the aid of a microscope. For both cases of the woven and the non-woven fabric, the skilled person knows how to determine said direction.

Woven fabrics generally contain at least two sets of yarns that are interlaced and lie at an angle to each other. A woven fabric can be characterized in most cases by a length L and a width W after being produced, wherein the term ‘after being produced’ is herein understood the fabric immediately after its production, e.g. before being cut or trimmed or otherwise processed after its production, In such a case, the fibers that run along the length L of the fabric are known as warps or warp ends while the fibers that run along or at an angle to the width W of the fabric are known as wefts or weft picks. In the case of woven fabrics the skilled person can immediately determine that a first majority of the fibers contained by said fabric may be the majority of fibers comprising the warps, while e.g. a second majority of the fibers may be the majority of fibers comprising the wefts. The skilled person can also immediately determine the orientation direction of the warps or of the wefts and he can use for example any of these directions as one of the orientation directions of a first majority of the fibers contained by said fabric.

Preferred embodiments of woven fabrics include plain (tabby) weaves, basket weaves, twill weaves, crow feet weaves and satin weaves although more elaborate weaves such as triaxial weaves may also be used. Preferably, the woven fabric is a basket weave, a plain weave or a twill weave.

In one embodiment of the invention, the fibers used to manufacture the woven fabric have a rounded cross-section, said cross section having an aspect ratio of at most 4:1, more preferably at most 2:1, and said fabric having a cover factor of at least 1.5, more preferably at least 2, most preferably at least 3. Preferably said cover factor is at most 10, more preferably at most 8, most preferably at most 6. It was observed that by using woven fabrics with a lower cover factors the 2D bending modulus may be improved. It was also observed that the sheets manufactured from such fabrics may have an increased homogeneity. However, handling of fabrics with a too low cover factor becomes difficult as such fabrics are sensitive to fiber shifts and thus to local variations in the final products’ mechanical properties.

In another embodiment of the invention, the woven fabric contained by the rigid sheet is a tridimensional (3D) woven fabric. It is known in the art how to produce such fabrics, for example from EP 0.548.517, US 6,627,562 and WO 02/07961. In a preferred embodiment the 3D woven fabric is a layered fabric comprising at least 2 layers, more preferably at least 3 layers. It was observed that in addition to an increase in the 2D bending modulus, a sheet containing such fabric may be less prone to delamination when subjected to bending forces.

Non-woven fabrics within the meaning of the present invention are fabrics produced by bonding and/or interlocking of fibers accomplished by e.g. inherent fiber-to-fiber friction (entanglement), mechanical, chemical, thermal or by solvent means and combinations thereof. The term non-woven fabric within the meaning of the present invention does not include fabrics that are woven, knitted or tufted.

Preferred embodiments of non-woven fabrics include various constrained or unconstrained arrangements of fibers including substantially parallel arrays, layered arrays with each layer having substantially parallel fibers and adjacent arrays being non-parallel to each other. A non-woven fabric may also be a fabric comprising one or more layers containing randomly oriented staple or continuous fibers. When the fabric contains substantially parallel arrays, the fibers direction in any of the arrays can be used as one of the orientation directions of a first majority of the fibers contained by said fabric. When the fabric contains randomly oriented fibers, any direction can be chosen as one of the orientation directions of a first majority of the fibers contained by said fabric.

The areal density (AD) of the fabric contained in the rigid sheet can vary within wide ranges. Preferably, the AD of said fabric is at least 100 g/m^2. Other suitable ADs of said fabric may be at least 300 g/m^2, or event at least 500 g/m^2. The upper limit for said AD is only dictated by practical reasons and is chosen by the skilled person with regard to the application for which the manufactured rigid sheet is intended. It is however preferred that said fabric has a lower AD since a lighter sheet of the invention can be obtained having also a suitable 2D bending modulus.

If the fabric is a woven fabric, the areal density of the woven fabric is preferably between 100 and 2000 g/m^2. Other preferred ADs for such a woven fabric may be between 200 and 1000 g/m^2 or even between 300 and 800 g/m^2. It was observed that for such areal densities an rigid sheet containing woven fabrics possessed an increased

2D bending modulus and was also lightweight.

The rigid sheet may also comprise various conventional additives and reinforcing agents to further enhance various characteristics of said sheet. For example the sheet may further contain additives e.g. pigments, antioxidants, UV stabilizers and delusterants in an amount of preferably from 1 to 15 mass%, more preferably from 2 to 5 mass% from the total mass of the sheet of the invention.

Preferably, the rigid sheet is a sheet having a length (L) and a width (W), wherein L and/or W are at least 0.5 m, more preferably at least 1 m, most preferably at least 1.5 m. More preferably, both L and W are at least 0.5 m, more preferably at least 1 m. The upper limits for L and W are dictated by the application for which the rigid sheet is intended. Preferably, the length L and/or the width W of the rigid sheet are at most 5 meter, more preferably at most 4 meters, most preferably at most 3 meters. Such large sized sheets, also known as panels, are more advantageous as construction materials because they can be easier and more rapidly installed and furthermore they are more efficient to produce.

In a preferred embodiment of the inventive system, the rigid sheet is translucent or transparent. The advantage thereof is that such systems can be placed in front of openings of the structure to be protected without impeding the light to enter the structure. The skilled person knows how to manufacture such rigid translucent or transparent sheets, e.g. from EP 0,116,845 by compressing layers of fabrics at elevated temperatures, e.g. at temperatures above the melting temperature of the fibers contained by said fabrics.

In a further preferred embodiment of the inventive system, the rigid sheet has at least one corrugated region. Examples of corrugated rigid sheets are given in US 6,974,622 the disclosure thereof being herein included by reference. It was observed that such a system has increased impact resistance to airborne heavy weight debris. Preferably the corrugated compressed rigid sheets of this embodiment are translucent or transparent. The skilled person can produce corrugated rigid sheets for example by using the method of GB 2,253,420 to compress a plurality of layers of fabric in an e.g. molding press, said press having a corrugated shape and therefore imparting corrugated regions to the obtained compressed rigid sheet.

The thickness of the sheet of the invention can vary within wide ranges and is dictated by the initial thickness, i.e. the thickness before compressing, of the fabric contained in said sheet and/or by the number of said fabrics and/or by the processing conditions, e.g. pressure and time.

Suitable high strength fibers for use in the fabric of the rigid sheet, also referred to herein simply as fibers, may be inorganic fibers, e.g. glass or carbon fibers, or organic fibers also referred to herein as polymeric fibers. Preferably, the fibers are polymeric fibers.

Suitable high strength polymeric fibers that may be used in accordance with the invention are fibers manufactured from polymers chosen from the group consisting of polyamides and polyaramides, e.g. poly(p-phenylene terephthalamide) (known as Kevlar®); poly(tetrafluoroethylene) (PTFE); poly{2,6-diimidazo-[4,5b-4',5'e]pyridinylene-1,4(2,5-dihydroxy)phenylene} (known as M5); poly(p-phenylene-2, 6-benzobisoxazole) (PBO) (known as Zylon®); poly(hexamethyleneadipamide) (known as nylon 6,6), poly(4-aminobutyric acid) (known as nylon 6); polyesters, e.g. poly(ethylene terephthalate), poly(butylene terephthalate), and poly(1,4 cyclohexylidene dimethylene terephthalate); polyvinyl alcohols; thermotropic liquid crystal polymers (LCP) as known from e.g. US 4,384,016 included herein by reference; but also polyolefins e.g. homopolymers and copolymers of polyethylene and/or polypropylene. Also combinations of fibers manufactured from the above referred polymers can be used to manufacture the fabric contained in the rigid sheet. Preferred fibers are those selected from the group consisting of polyolefin fibers, polyamide fibers, LCP fibers and combinations thereof.

By fiber is herein understood an elongated body, the length dimension of which is much greater that the transverse dimensions of width and thickness. The term fiber also includes various embodiments e.g. a filament, a ribbon, a strip, a band, a tape and the like having regular or irregular cross-sections. The fibers may have continuous lengths, known in the art as filaments, or discontinuous lengths, known in the art as staple fibers. Staple fibers are commonly obtained by cutting or stretch-breaking filaments. A yarn for the purpose of the invention is an elongated body containing many fibers.

Best results were obtained when the high strength polymeric fibers are polyolefin fibers, more preferably polyethylene fibers. Preferred polyethylene fibers are ultrahigh molecular weight polyethylene (UHMWPE) fibers. Said polyethylene fibers may be manufactured by any technique known in the art, preferably by a melt or a gel spinning process. Most preferred fibers are gel spun UHMWPE fibers, e.g. those sold by DSM Dyneema under the name Dyneema®. If a melt spinning process is used, the polyethylene starting material used for manufacturing thereof preferably has a weight-average molecular weight between 20,000 and 600,000, more preferably between 60,000 and 200,000. An example of a melt spinning process is disclosed in EP 1,350,868 incorporated herein by reference. If the gel spinning process is used to manufacture said fibers, preferably an UHMWPE is used with an intrinsic viscosity (IV) of preferably at least 3 dl/g, more preferably at least 4 dl/g, most preferably at least 5 dl/g. Preferably the IV is at most 40 dl/g, more preferably at most 25 dl/g, more preferably at most 15 dl/g. Preferably, the UHMWPE has less than 1 side chain per 100 C atoms, more preferably less than 1 side chain per 300 C atoms. Preferably the UHMWPE fibers are manufactured according to a gel spinning process as described in numerous publications, including EP 0205960 A, EP 0213208 A1, US 4413110, GB 2042414 A, GB-A-2051667, EP 0200547 B1, EP 0472114 B1, WO 01/73173 A1, EP 1,699,954 and in "*Advanced Fibre Spinning Technology*", Ed. T. Nakajima, Woodhead Publ. Ltd (1994), ISBN 185573 182 7.

In a preferred embodiment, at least 80 mass%, more preferably at least 90 mass%, most preferably 100 mass% of the fibers in the fabrics used to manufacture the compressed rigid sheet are UHMWPE fibers. It was observed that the inventive systems comprising compressed rigid sheet containing such fabrics showed also good resistance to sun light and UV degradation. The remaining of the fibers are preferably fibers manufactured from any of the polymeric materials disclosed hereinabove, preferably aramid fibers.

In a special embodiment of the present invention, the fiber is a tape. The tape is preferably manufactured from polyolefin, more preferably from UHMWPE. A tape for the purposes of the present invention is a fiber with a cross sectional aspect ratio of at least 5:1, more preferably at least 20:1, even more preferably at least 100: 1 and yet even more preferably at least 1000:1. Preferably the tape has a width of between 1 mm and 600 mm, more preferable between 1.5 mm and 400 mm, even more preferably between 2 mm and 300 mm, yet even more preferably between 5 mm and 200 mm and most preferably between 10 mm and 180 mm. Preferably the tape has a thickness of between 10 μm and 200 μm and more preferably between 15 μm and 100 μm.

A preferred process for the formation of such tapes comprises feeding a polymeric powder between a combination of endless belts, compression-moulding the polymeric powder at a temperature below the melting point thereof and rolling the resultant compression-moulded polymer followed by drawing. Such a process is for instance described in EP 0 733 460 A2, which is incorporated herein by reference. If desired, prior to feeding and compression-moulding the polymer powder, the polymer powder may be mixed with a suitable liquid organic compound having a boiling point higher than the melting point of said polymer. Compression moulding may also be carried out by temporarily retaining the polymer powder between the endless belts while conveying them. This may for instance be done by providing pressing platens and/or rollers in connection with the endless belts. Preferably solid state drawable UHMWPE is used in this process. Examples of commercial available solid state drawable UHMWPE includes GUR 4150(TM), GUR 4120(TM), GUR 2122™, GUR 2126 ™ manufactured by Ticona; Mipelon XM 220 ™ and Mipelon XM 221U ™ manufactured by Mitsui; and 1900 ™, HB312CM ™, HB320CM ™ manufactured by Montell.

Preferably, the fibers have a tensile strength as measured according to ASTM D2256-02(2008) of at least 0.3 GPa, more preferably at least 0.8 GPa, more preferably at least 1.2 GPa, more preferably of at least 2.5 GPa, most preferably of at least 3.5 GPa. Preferably, the fibers have a tensile modulus as measured according to said ASTM D2256 of at least 30 GPa, more preferably of at least 50 GPa, most preferably of at least 60 GPa. Best results were obtained when the fibers were UHMWPE fibers having a tensile strength of at least 2 GPa, more preferably at least 3 GPa and a tensile modulus of at least 40 GPa, more preferably of at least 60 GPa, most preferably at least 80 GPa. If the fiber is a tape, the tensile strength and or modulus of a tape may be determined in accordance to any known method in the art, e.g. by puling an e.g. 25 cm long tape clamped in barrel clamps at a rate of e.g. 25 cm/min on an Instron Tensile Tester.

Preferably, the compressed rigid sheet comprises an ultraviolet (UV) light-resistant material. The UV resistance of a material is measured as the time required for the material to loose 50% of its initial modulus when exposed to UV radiation. The use of a material with a relatively high UV resistance extends the usable life of the sheet. The UV resistant material can be included into the sheet for example as a matrix material by laminating or impregnating the layers of fabric with said material prior to compression or even being laminated directly to the compressed riding sheet on the side of said sheet exposed to UV radiation. Examples of UV resistant material include polyvinyl fluoride (PVF) sold by Dupont under the name of Tedlar®.

A preferred method of manufacturing a rigid sheet to be used as the strike face in the panel of the invention comprises the steps of:

a) Providing at least one sheet comprising at least one woven or non-woven fabric, said fabric comprising polymeric fibers;
b) Using compressing means to apply a contact pressure of between 60 bar and 500 bar to said sheet;
c) Heating the sheet to an elevated temperature (T) with a heat up rate of between 3°/min and 200°/min while applying said contact pressure, said elevated temperature being below the peak temperature of melting (T_m) of said fibers, said T_m being determined by DSC under restrained conditions;
d) Keeping the sheet under the contact pressure and at the elevated temperature for a period of time of between 5 and 300 minutes;
e) Subsequently cooling down the sheet with a cooling rate of between 3°/min and 200°/min while maintaining the contact pressure and the elevated temperature; and
f) Releasing the compressing means not earlier than from the moment when the sheet reached a temperature of between 50°C and 90°C.

The process of the invention may be carried out using conventional compressing means, e.g. any press able to reach a compression pressure of at least 500 bar and being suitable to be heated up to a set temperature of at least 400°C. Such means are well known in the art and commercially available, examples thereof including presses sold by Bürkle, Fontijne or Siempelkamp. 1 bar is approximately equal to 0.1 MPa.

Preferably, the contact pressure applied at step b) of the process of the invention is between 80 and 450 bar; more preferably between 100 and 400 bar; even more preferably between 150 and 350 bar, most preferably between 250 and 350 bar. It was observed that for such high contact pressures the sheets of the invention showed an increased 2D bending modulus as well as a high flexural strength.

In a preferred embodiment, step b) of the process is carried out in a press preheated at a preheat temperature of between 60 and 130°C, more preferably of between 80 and 120°C, most preferably between 85 and 110°C. Preferably, the sheet is kept in the preheated press at the preheat temperature for a period of time between 2 and 50 minutes, more preferably between 5 and 30 minutes, most preferably between 10 and 20 minutes before applying the contact pressure. Pressing equipment having preheating capabilities is long known in the art, e.g. those enumerated hereinabove.

In a further embodiment, the temperature of the sheet before applying the contact pressure is between 30 and 100°C, more preferably of between 50 and 90°C, even more preferably between 70 and 85°C. The sheet can be heated in e.g. a conventional oven or by using infrared (IR) lamps and then immediately transferred to the pressing equipment. It was observed that for this embodiment, said homogeneity may be further improved but also the compression time at step e) of the process needed to achieve high 2D bending modulus may be reduced.

According to the process, the sheet is heated up in step c) of the process to an elevated temperature while applying a contact pressure thereof. The sheet is usually heated by heating the compressing means, e.g. the platens of a press, which in turn heat up said sheet. For some compressing means, a difference between the elevated temperature set on said means and the elevated temperature reached by the sheet may arise, said difference stemming from a poor heat transfer between said means and the sheet. The temperature of the sheet can be measured for example by a thermocouple placed on top or between the fabrics used to construct the rigid sheet. If such a difference arises the temperature of said means can be routinely adjusted such that the sheet is heated up at the elevated temperature required by the step c) of the process.

According to the process of the invention the sheet is heated in step c) under the contact pressure up to an elevated temperature (T) below the peak temperature of melting (T_m) of said fibers, the T_m being determined by DSC under restrained conditions. It was observed that the T_m of the fibers may increase when the fibers are under restrained conditions, e.g. when the fibers are built into a fabric and the fabric is subjected to a contact pressure like in step c) of the process of the invention. Preferably the elevated temperature T satisfies the following conditions: T_m - 30°C < T < T_m; more preferably T_m - 20°C < T < T_m - 3°C; most preferably T_m - 10°C < T < T_m - 3°C. In the case when the polymeric fibers do not allow a precise determination with DSC of said peak temperature of melting (T_m), said T_m is considered as the temperature at which the fiber breaks when it is placed under a load equal to 2% of its normal tensile strength, said normal tensile strength being the strength measured according to ASTM D2256 at room temperature (20°C).

It was observed that by carefully choosing the elevated temperature (T) and the contact pressure as well as the other parameters of the process, the occurrence of a second polymeric phase with a low melting temperature due to secondary recrystallizations of the polymeric chains may be avoided. The presence or absence of such a second phase may be readily investigated e.g. by DSC measurements and in particular as detailed in GB 2,253,420.

Preferably the heat up and the cool down rates in steps c) and e) of the process of the invention are between 5°/min and 100°/min, more preferably between 5°/min and 50°/min, respectively. It was observed that by choosing such ramps a sheet having in particular an increased 2D bending modulus but also an increased homogeneity of said modulus may be obtained.

Preferably the sheet is kept under the contact pressure for a period of time of between 10 and 200 minutes; more preferably between 15 and 100 minutes; more preferably between 20 and 50 minutes. Required times will increase with increasing the thickness of the fabric or the number of fabrics used at step a) of the process. It was observed that for said time periods the thickness variation of the rigid sheet may be reduced.

Good results were obtained when the sheet of step a) of the process was kept at an elevated temperature under a contact pressure of between 150 and 350 bar for a period of time of between 20 and 50 minutes. Preferably, the sheet contained at least one fabric comprising UHMWPE fibers, more preferably, the fabric or the fabrics contained by said sheet are manufactured substantially entirely from UHMWPE fibers.

In a further preferred embodiment, the fibers contained by at least one fabric of the sheet of the invention are polyethylene fibers, more preferably UHMWPE fibers, even more preferably said UHMWPE fibers being UHMWPE tapes and the fabric is preferably heated in step c) of the process to an elevated temperature T between 133 and 158°C, more preferably of between 135 and 157°C, even more preferably between 137 and 146°C, most preferably between 153 and 156°C and wherein at step d) of the process the sheet is kept under the contact pressure for a period of time of between 5 and 300 minutes and wherein the elevated temperature T preferably rose during said period in a step-wise profile. Preferably, at said step d), said period of time was between 30 and 70 minutes. Preferably the elevated temperature T rose with at least 10% per step in at least one step, more preferably rose with at most 3% per step in at least 2 steps. It was observed that under these processing conditions the 2D bending modulus of the sheet of the invention may even be further increased.

The contact pressure is released at step e) of the process not earlier than when the sheet is cooled down to between 50°C and 90°C, preferably between 60°C and 85°C, more preferably between 70°C and 80°C. It was observed that by releasing the contact pressure at said temperatures, sheets with improved mechanical properties in multiple directions may be obtained.

The process may further comprise a further lamination step wherein multiple sheets according to the invention are laminated together. The process may also comprise a moulding step wherein the sheet is imparted at least one curvature or it is imparted local areas that are raised or lowered with respect to the surrounding area. Such a moulding step can be carried out with conventional moulding equipment wherein the sheet is compressed between two surfaces, at least one containing the features that are desired to be transferred to said sheet, e.g. local areas, curvatures in at least one directions, etc. Alternatively, the compression step b) in the process can be carried out in such conventional moulding equipment.

In a preferred embodiment of the inventive system, the panel comprises a strike face, said strike face containing a plurality of preferably interlocking or overlapping compressed rigid sheets. It was observed that such a system can be successfully used as a shutter system for windows and doors, is lightweight and can be easily mounted and deployed when the threat of a storm arises. Therefore, the invention also relates to a shutter system for protecting a structure, preferably for protecting an opening in a structure, said shutter system comprising at least one panel, said panel comprising a strike face for receiving an impact wherein said strike face comprises at least one substantially rigid sheet containing a plurality of fabric layers, said fabric layers being compressed at an elevated temperature to form said rigid sheet, said fabric containing high strength polymeric fibers. Preferably, the shutter system of the invention is a folding or a roll-up shutter, more preferably the shutter system of the invention is a shutter having a construction according to US 6,189,264 included herein by reference.

According to the invention, the protective system comprises means for attaching said system to or for positioning the system in close proximity to said structure. Such means are well known in the art and include grommets; nuts and bolts; pairs of mounting tracks; fasteners; hangers attaching the system to tracks, e.g. J-type, H-type, inverted H-type of tracks; shock adsorbing connectors and the like. Preferably grommets are used due to their increased handleability. Examples of such means are given in US 6,502,355; US 6,189,264; US 6,974,622; US 2003/0159372 the disclosure thereof being included herein by reference. By attaching the system to a structure it is herein understood that the system is in touching proximity with said structure. By attaching the system in close proximity to a structure is herein understood that the system is attached in front of the structure at a distance close enough to said structure to prevent debris impacting the structure. The skilled person can routinely determine said distance.

The invention further relates to a structure, in particular a building or a dwelling, comprising the inventive system.

The invention also relates to a method for protecting a structure against high winds, comprising placing a system as described in the above on the structure.

The invention further relates to a method of mounting the inventive system to a structure, the method comprising connecting the system according to the invention to or in close proximity to said structure. In a preferred embodiment, the system is position such that the panel is at an angle of between 5 and 15° with the vertical. It was observed that such a positioning reduces the risk of penetration of said panel by sharp objects.

In another preferred embodiment of the method according to the invention, the inventive system is mounted such that the panel is positioned in front of a door or a glass window of a building. It was observed that such a positioning is very effective in stopping debris from entering the building and from damaging the doors and the windows of a building.

MEASUREMENT METHODS

Cover factor: of a woven fabric is calculated by multiplying the average number of individual weaving yarns per centimeter in the warp and the weft direction with the square root of the linear density of the individual weaving yarns (in tex) and dividing by 10.
An individual weaving yarn may contain a single yarn as produced, or it may contain a

plurality of yarns as produced which are assembled into the individual weaving yarn prior to the weaving process. In the latter case, the linear density of the individual weaving yarn is the sum of the linear densities of the as produced yarns.

The cover factor (CF) can be thus computed according to formula:

$$CF = \frac{m}{10}\sqrt{pt} = \frac{m}{10}\sqrt{T}$$

wherein m is the average number of individual weaving yarns per centimeter, *p* is the number of as produced yarns assembled into a weaving yarn, *t* is the linear density of the yarn as produced (in tex) and *T* is the linear density of the individual weaving yarn (in tex).

AD: was determined by measuring the weight of a sample of preferably 0.4 m × 0.4 m with an error of 0.1 g.

Intrinsic Viscosity (IV): for polyethylene is determined according to method PTC-179 (Hercules Inc. Rev. Apr. 29, 1982) at 135°C in decalin, the dissolution time being 16 hours, with DBPC as anti-oxidant in an amount of 2 g/l solution, by extrapolating the viscosity as measured at different concentrations to zero concentration.

T_m: The representative sample used consisted of 10 mg of the fiber which was wound on a cylindrical aluminum spool having a diameter of 5 mm and a height of 2 mm. The ends of the fibers were fixated by knotting. A stress of about 0.05 N/tex was applied during winding.

The peak temperature of melting of the fiber under restrained conditions was determined by DSC on a power-compensation PerkinElmer DSC-7 instrument which is calibrated with indium and tin with a heating rate of 10°C/min. For calibration (two point temperature calibration) of the DSC-7 instrument about 5 mg of indium and about 5 mg of tin are used, both weighed in at least two decimal places. Indium is used for both temperature and heat flow calibration; tin is used for temperature calibration only.

The furnace block of the DSC-7 is cooled with water, with a temperature of 4°C in order to provide a constant block temperature, for a stable baselines and good sample temperature stability. The temperature of the furnace block should be stable for at least one hour before the start of the first analysis.

The representative sample is put into an aluminum DSC sample pan (50 μl), which is covered with an aluminum lid (round side up) and then sealed. In the sample pan (or in the lid) a small hole must be perforated to avoid pressure build-up (leading to pan deformation and therefore a worsening of the thermal contact).

The sample pan is placed in a calibrated DSC-7 instrument, said instrument also containing in the reference furnace a sample pan (also covered with a pierced lid and sealed) containing the aluminum spool without fibers.

A standard DSC temperature program is used dependant on the fibers to be analyzed. In case of UHMWPE fibers, the following temperature program is run:

1. sample is kept for 5 min at 40°C (stabilization period)
2. increase temperature from 40 up to 200°C with 10°C/min. (first heating curve)
3. sample is kept for 5 min at 200°C
4. temperature is decreased from 200 down to 40°C (cooling curve)
5. sample is kept for 5 min at 40°C
6. optionally increase temperature from 40 up to 200°C with 10°C/min to obtain a second heating curve.

The same temperature program is run with a pan containing an empty spool fitting in the sample side of the DSC furnace (empty pan measurement).

Analysis of the first heating curve is used as known in the art to determine the peak temperature of melting of the analyzed fiber. Futhermore, the heat of fusion ΔH may be obtained by integrating the peakarea, as is commonly known in the art. Furthermore the crystallinity of UHMWPE fibers may be calculated by dividing the ΔH by 293 J/g, which is the heat of fusion of a pure UHMWPE polymeric crystal.

The empty pan measurement is subtracted from the sample curve to correct for baseline curvature. Correction of the slope of the sample curve is performed by aligning the baseline at the flat part before and after the peaks (at 60 and 190°C for UHMWPE). The peak height is the distance from the baseline to the top of the peak.

<u>Peeling force</u>: is the force (in grams) needed to pull off a sticker adhered to the surface of the sheet by pulling it along its length direction at an angle of 90° with respect to the surface of the sample. The sticker used was an “Avery Graphics 400 Permanent” 5 × 16 cm size sticker and was placed onto the surface of the sheet by pressing uniformly over

the surface of said sticker with a force of about 5 Kg for about 1 minute.

Deflection: was measured with a 3-point bending test according to ISO 178 standard and quantified as the force needed to induce a 20 mm deflection in the testes sample. The test speed was 1 mm/min, the width of the sample was 25 ± 0.5 mm, the width over thickness ratio was about 70, the radius of the loading edge was 5 mm and the radius of the supports was 2 mm.

Impact energy: was measured according to formula below

$$\textit{Impact energy} = m \cdot g \cdot h$$

by dropping from different heights (h) a hemispherical dart having a radius of 4.9 mm and a mass (m) of 4.93 Kg. g is the gravitational acceleration and equals 9.81 m/sec^2. 5 impacts were carried out for each sample and the results averaged. The height was increased until full penetration of the dart through the sample was achieved. The height at which full penetration was achieved was called Fall Height Stop. The impact energy is the energy required to induce a full penetration of the sample in 50% of the impacts.

EXAMPLE AND COMPARATIVE EXPERIMENT

From the Example presented herein below could have been concluded that an inventive system comprising a panel consisting of rigid sheets obtained as detailed hereinafter resists to impacts from heavy and sharp airborne debris better than a protective system containing a panel manufactured from an aluminum plate. In addition, the inventive system had a smaller weight than the latter system.

EXAMPLE

A rigid sheet was obtained by compressing 3 layers of a basket weave fabric constructed from UHMWPE fibers, said fibers being sold by DSM Dyneema under the name of Dyneema® SK 75. Each layer of the basket weave fabric had an areal density of about 347 g/m^2, a cover factor of about 5.9 and a thickness before compaction of about 0.5 mm. The layers of fabric were positioned such that the direction of the warp yarns in a layer of fabric was at an angle of 90° to the direction of the warp yarns in an adjacent layer of fabric.

The layers of fabric were compressed in a steam heated Fontijne press at a contact pressure of 25 bar and at a temperature as measured with a thermocouple placed between the layers of fabric of 152°C. Subsequently, the obtained rigid sheet was cooled down to 20°C with a cool down rate of about 20°C/minute, the press being released at a temperature of about 20°C.

The bending modulus of the rigid sheet was 13.08 GPa, the impact energy was 21.2 J and the fall height stop was 50 cm.

A number of 5 rigid sheets were used to assemble a panel by positioning the sheets on top of another, the obtained panel being lightweight and easy mountable by a single person.

COMPARATIVE EXPERIMENT

A panel was constructed from a rigid sheet of aluminum having a thickness of 0.76 mm and the same dimensions as the panel of the Example. The bending modulus of the rigid aluminum sheet was 69.45 GPa, the impact energy was 16.46 J and the fall height stop was 34 cm.

CLAIMS

1. A system for protecting a structure against high winds of a hurricane category, said system comprising at least one panel, said panel comprising a strike face for receiving an impact and furthermore said system comprising means for attaching the system to or for positioning the system in close proximity to said structure, characterized in that said strike face comprises a compressed sheet, said sheet being substantially rigid and wherein said sheet contains a plurality of layers of fabric, said fabric containing high strength fibers.
2. The system according to claim 1 wherein the high strength polymeric fibers are ultrahigh molecular weight polyethylene (UHMWPE) fibers.
3. The system according to any of the preceding claims wherein the sheet has a bending modulus of at least 2 GPa, preferably at least 5 GPa as measured according to ASTM D790-07.
4. The system according to claim 3, wherein the sheet has a bending modulus of at least 15 GPa when measured according to ASTM D790-07 in at least two directions and wherein one of said directions is the orientation direction of a first majority of the fibers contained by said at least one woven or non-woven fabric.
5. The system according to any of the preceding claims, wherein the sheet contains one fabric.
6. The system according to any of the preceding claims, wherein the sheet contains a woven fabric.
7. The system according to any of the preceding claims wherein the system is position such that the rigid sheet is at an angle of between 5 and 15° with the vertical.
8. The system according to any of the preceding claims wherein said system is positioned in front of a door or a glass window of a building.
9. Method for protecting a structure against high winds, comprising placing a system according to any of the preceding claims on the structure.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2010/058233

A. CLASSIFICATION OF SUBJECT MATTER
INV. E06B9/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
E06B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2006/086057 A1 (RASENBERGER KURT E [US] ET AL) 27 April 2006 (2006-04-27) paragraphs [0026], [0027]; claims 1-3; figures 1-4	1-3,5,6, 8,9
Y	WO 2009/008922 A2 (BAE SYSTEMS TENSYLON HIGH PERF [US] BAE SYSTEMS TENSYLON HIGH PERF [US) 15 January 2009 (2009-01-15) page 20; claims 1,5	1,5,6,8, 9
Y	WO 2007/122010 A2 (DSM IP ASSETS BV [NL]; MARISSEN ROELOF [NL]; SIMMELINK JOSEPH ARNOLD P) 1 November 2007 (2007-11-01) page 16	2,3

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 July 2010	30/07/2010

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 2003/134091 A1 (WADE ASHLEY [US]) 17 July 2003 (2003-07-17) cited in the application * abstract; figure 5	1-9

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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